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Investigation of temporal and spatial variations of meteorological drought in Lorestan province[1]

Yaser Sabzevari[1], Saeid Eslamian[2]

[1] Ph.D. Student, Department of Water Engineering, Isfahan University of Technology, Isfahan, Iran **(Corresponding Author).** yas.sabzevari@gmail.com

[2] Professor, Department of Water Engineering, Isfahan University of Technology, Isfahan, Iran. Saeid@iut.ac.ir

Abstract

Introduction: Drought is a deficiency in precipitation over an extended period. It is a part of normal climate variability in many climate zones. The duration of droughts varies widely. Drought can develop quickly and last only for a matter of weeks, exacerbated by extreme heat and/or wind, but more commonly drought can persist for months or years. Decreased rainfall and severe fluctuations in rainfall are factors that have exacerbated the water crisis in recent years, as well as numerous droughts. Drought is one of the most important natural disasters that is called lack of rainfall in a long period Drought is a natural phenomenon that has a significant impact on Human life exists and its temporal and spatial variations can be effective in dealing with the effects of this phenomenon. The purpose of this study was to investigate the drought process using SPI and Mann-Kendal test as well as meteorological drought spatial variations in Lorestan province using GIS.

Materials and Methods: Drought is often grouped into four basic types: 1) meteorological or climatological, 2) agricultural, 3) hydrological, and 4) socioeconomic. Meteorological and climatological drought is defined in terms of the magnitude of a precipitation shortfall and the duration of this shortfall event. Lorestan province with an area of 28064 km in western Iran is located between 46 degrees and 51 minutes to 50 degrees and 3 minutes' east longitude of the Greenwich meridian and 32 degree and 37 minutes and 34 degrees and 22 minutes north latitude of the equator.

The Standardized Precipitation Index (SPI) was developed to determine drought and wetness at each station, and the values obtained (SPI) indicate different intensities of

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drought in an area. The Standard Precipitation Index (SPI) is a relatively new drought index based only on precipitation. It's an index based on the probability of precipitation for any time scale. Some processes are rapidly affected by atmospheric behavior, such as dry land agriculture, and the relevant time scale is a month or two.

Results and Discussion: Using SPI index, rainfall data of 9 synoptic stations and 23 rain gauging stations in the statistical period (1998-2018) were analyzed at the provincial level. The Mann-Kendal test was used to examine the trend of annual changes and the appropriate interpolation method was used to prepare zoning maps using the information of all 32 stations. The Mann-Kendal test is used to check the time trend for each set of data. This test is based on non-parametric linear regression logic. In this study, for interpolation, the methods of inverse distance weighting, Global polynomials, local polynomials, radial basis functions and kriging were investigated and the most accurate method was selected.

Mann-Kendal test results showed that the trend of drought index changes of Alashtar at the 95% probability level was significant and increasing and the rest of cities lacked Are meaningful. The results indicate that according to the value classification scale (SPI), Aligudarz city was very dry in 1999 and 2008, with moderate humidity in 2017 and moderate drought in 2000 and in the other years has been in normal condition. The most suitable method was Kriging method for zoning drought in the province. For this purpose, the years 2012, 2016 and 2018 were designated as representative of the dry, wet and normal years, respectively. According to the zoning maps mentioned in three years, in the year 2012 districts west and south have been subjected to severe drought, in the northern part of the province in the wet period in the year 2016, and in the eastern part of the province in the year 2018 have been most exposed to drought. Also, considering the number of droughts in different years for the selected stations, the driest station, Kohdasht station and the humidest station, Nourabad station was introduced.

Conclusions: Based on result of study, the driest station can be introduced as Koohdasht and the wettest station can be introduced as Noorabad. According to the results of this study and the occurrence of various droughts in different parts of the province, to deal with the effects of this phenomenon, proper planning of water resources and insurance of agricultural products, especially in the city of Koohdasht, which more than other parts of the province with Drought has been suggested.

Keywords: Kriging, Mann-Kendal test, SPI drought index, Zoning.

1. Introduction

Today, the importance of water has increased due to increasing population and global warming and over-exploitation of environmental resources, as well as reduced rainfall compared to previous years. Decreased rainfall and severe fluctuations in rainfall are factors that have exacerbated the water crisis in recent years, as well as numerous droughts. Drought is one of the most important natural disasters that is called lack of rainfall in a long period (Mahmoudi *et al*., 2015; Tanni *et al*., 2021).

According to the researchers, drought is divided into different types based on the studied parameters: meteorological, agricultural, hydrological and socio-economic drought (Ghainati *et al*., 2018; Tigkas *et al*., 2016; Delpla *et al*., 2009). Meteorological drought occurs before other droughts and is followed by other types of droughts. Meteorological drought with a time delay in one place leads to agricultural droughts and then to hydrological droughts (Mahmoudi *et al*., 2015).

One of the basic steps in drought and wetland studies is to determine the indicators on the basis of which the severity and continuity of drought and wetland can be assessed. Standard Precipitation Index (SPI) is one of the most comprehensive drought and wetland study indices that has been used in most parts of the world as a suitable indicator for drought monitoring (Ellis *et al*., 2010; Hao & Singh, 2013; Mishra & Singh, 2010).

Studying the spatial and temporal changes of drought can be effective in providing better solutions for natural management and planning (Abedzadeh, 2018). There are several methods for examining spatial and temporal variations, including the Mann-Kendall trend analysis test, which is a non-parametric test, and the GIS, which has good spatial and temporal capabilities. Numerous studies have been conducted in this field, which are mentioned below.

McKee *et al*. (1993) presented the Precipitation Index for Drought Monitoring and used the index to monitor drought in Colorado. Mishra & Desai (2005) studied the spatial and temporal drought of the Kansabati River Plain of India using index (SPI) and GIS and the results showed that severe drought occurred in 1980. Rahman & Lateh (2016) evaluated the Meteorological drought in Bangladesh. The results showed that the northern, northwestern, western, southwestern and central regions were the most drought-prone regions in terms of occurrence and severity, respectively.

Suryabhagavan (2017) analyzed GIS-based climate change and drought characteristics by the SPI index in Ethiopia from 1983 to 2012, the results showing that among the major droughts, annual droughts 1985-1984 was reported as a severe drought in Wollo. Khubaib *et al*. (2019) assessed drought risk using satellite remote sensing and geographical methods in the Khoshab region of Pakistan and also used values (SPI) to control meteorological drought. The results show that 30.21% of the region has moderate drought and the severity of drought in the southern part of *Khoshab region is higher than the northern part*.

Aladaileh et al. (2019) examined the spatial and temporal variations of drought in Jordan using the Mann-Kendal test and the Kriging interpolation method. The results showed that according to Mann-Kendal test, there was a decreasing trend for all stations except Madaba and also meteorological drought occurred. Shahian *et al*. (2009) used rainfall index (GIS) to study the drought situation in Fars province in Iran. The results showed that the southern and eastern regions and some western and central regions have more drought than other parts of the province and more drought have been mild drought. Tatina *et al*. (2010) studied drought in Gilan province in Iran in a statistical period of 30 years. The results showed that drought occurred intermittently with relatively regular cycles in the region and also the spatial and temporal pattern of drought after monitoring, Indicates the occurrence of continuous and intermittent droughts in the study area, which creates critical conditions for natural and human resources.

Khosravani *et al*. (2013) by studying the statistics of six meteorological stations in Khuzestan province in Iran with a statistical period of 25 years on an annual time scale showed that the lowest and highest value (SPI) is related to the city of Ahvaz. Hejazizadeh *et al*. (2014) studied drought in Kerman Province in Iran and used Mann-Kendal test to study changes in its trend. The results showed that the trend of changes in spring rainfall in Kerman province is significant and also the spring season is changing to dry periods. Malekinejad *et al*. (2015) studied four synoptic stations in Tehran province in Iran and the trend of changes was examined by Mann-Kendall and Sen tests. The results showed that there is no specific trend in the seasonal time series, but for the monthly data in most stations, according to the Mann-Kendal test, it has a significant and upward trend.

Kowsari *et al*. (2016) studied drought in arid, semi-arid and ultra-arid regions of the world. The results showed that the range of long-term moderate to severe and also very severe droughts is observed in some parts of the world, especially in the Middle East and West America. Also, the trends are increasing and decreasing significantly. The need to deal with the various effects of drought makes it necessary to be aware of the past situation of different regions in terms of drought. Therefore, the purpose of this study is to monitor the annual meteorological drought and to study the trend of its 21-year changes and its zoning in Lorestan province in Iran in 3 years as a representative of wet, normal and dry years in terms of drought, using the geographical information system.

2. Materials and methods

2-1. study area

Lorestan province with an area of 28064 km in western Iran is located between 46 degrees and 51 minutes to 50 degrees and 3 minutes east longitude of the Greenwich meridian and 32 degree and 37 minutes and 34 degrees and 22 minutes north latitude of the equator. Its height from sea level varies from the highest point with an altitude of 4050 to the lowest point in the south of the province with an altitude of 500 meters. The capital of this province is Khorramabad city. Figure 1 shows the map of Lorestan province and the location of the studied stations.

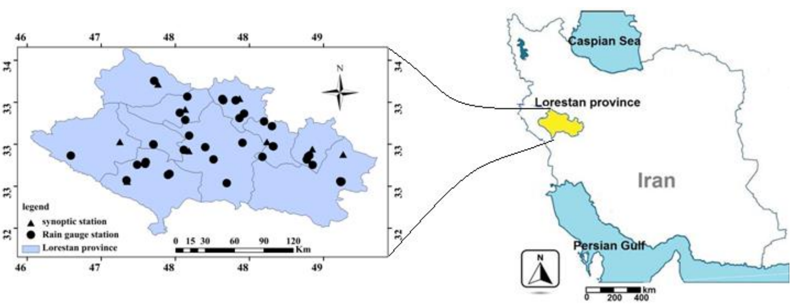


Fig 1. Geographical location of Lorestan province and the studied stations

In this study, to monitor the annual meteorological drought in Lorestan province, 21-year rainfall data (2018-1998) related to 9 synoptic stations and 23 rain gauge stations in the province were used. This statistic is from Lorestan Meteorological Organization and Water Company Areas of Lorestan province was taken. The Mann-Kendal test was used to examine the trend of annual changes and the appropriate interpolation method was used to prepare zoning maps using the information of all 32 stations. Table 1 shows the characteristics of 9 meteorological stations studied in this research in Lorestan province.

Table 1. Details of meteorological stations in Lorestan province

Station name	Longitude	latitude	Height (m)	Average annual rainfall (m)	Station type
Azna	49° 25′	33° 27′	1872	409.6	Synoptic
Sekseleh	48° 15′	33° 49′	1567	444.1	Synoptic
Aligudarz	49° 42′	33° 24′	2022	387.7	Synoptic
Boroujerd	48° 45′	33° 35′	1629	456.2	Synoptic
Poldokhtar	47° 43′	33° 09′	713	358.8	Synoptic
Khorramabad	45° 17′	33° 26′	1148	499	Synoptic
Doroud	49° 04′	33° 29′	1527	627.1	Synoptic
Koohdasht	47° 39′	33° 31′	1198	365.8	Synoptic
Noorabad	48° 00′	33° 03′	1860	465.8	Synoptic

2-2. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee *et al*. (1993) to monitor drought conditions in Colorado. McKee and colleagues set up a classification system to determine drought and wetness at each station, and the values obtained (SPI) indicate different intensities of drought in an area. Another feature is that based on this method, the drought threshold can be determined for each time period. Therefore, in addition to the severity of the drought, its duration can also be determined based on this index. The standardized rainfall index is based on the probability of rainfall for each time period. This index is designed to minimize the lack of rainfall in multiple time periods. These different time scales express the special effects of drought on access to different water resources.

$$SPI = \frac{X_i - \bar{X}}{S_X} \qquad (1)$$

Where:

X_i= Rainfall per month.

$\bar{X}$ = Average rainfall on a time scale.

S_X = is the standard deviation of rainfall on a time scale.

Table 2 is proposed to classify the SPI method.

Table 2. Classification scale of SPI values

class	Extremely dry	Very dry	Medium dry	Almost normal	Medium wet	Very wet	Extremely wet
SPI values	<−2	-1.99 to -1.49	−1 to −1.49	to 0.99 −0.99	1 to 1.49	1.5 t 1.99	>2

2-3. Mann-Kendal Test

The Mann-Kendal test is used to check the time trend for each set of data. This test is based on non-parametric linear regression logic. The results of this test show whether there is a significant increase or decrease trend in a certain level of confidence in the time series trend of the parameter under study. Using Mann-Kendal nonparametric test is not sensitive to the normality of the data. The Mann-Kendall test was first proposed by (Mann, 1945) and then developed by (Kendal, 1975). The use of this method was recommended by the World Meteorological Organization (Soltanigordfaramarzi *et al*., 2017). One of the strengths of the Mann-Kendal method is that it is suitable for time series that do not follow a specific distribution.

This method is used to examine the trend of data. In this method, the S statistic for the g th month and the k th station is calculated as follows:

$$S_{gk} = \sum_{i}^{n-1} \sum_{j=i+1}^{n-1} \text{sgn}\,(X_{jgk} - X_{igk}),\ \forall \leq i < j \leq n \qquad (2)$$

Where n is the number of series data and sgnθ is a function of the sign and θ is the difference between the two observations in each of the studied parameters in different years i and j, which are as follows Defined:

$$\text{Sgn}(\theta) = \begin{cases} 1 & \text{if} \quad \theta > 0 \\ 0 & \text{if} \quad \theta = 0 \\ -1 & \text{if} \quad \theta < 0 \end{cases} \qquad (3)$$

Kendall and I showed that when $n \geq 10$, the S statistic is distributed almost normally and has a mean of 0 and the following standard deviation:

$$(\sigma_{gg})_k = \frac{[n(n-1)(2n+5) - \sum d(d-1)(2d+5)]}{18} \qquad (4)$$

Where d is the same number of data in the time series. In this method, Sgk is normalized as follows:

$$S'_{gk} = S_{gk} - \text{sgn}(S_{gk}) \qquad (5)$$

Then the standardized test statistic or Z, which has a standard normal distribution with a mean of 0 and a variance of 1, is obtained as follows:

$$Z_{gk} = \frac{S'_{gk}}{(\sigma_{gg})^{1/2}} \qquad (6)$$

If the value of Z is greater than ± 1.96, the data has a trend and the null hypothesis is rejected, otherwise it has no trend. Z is the standard normal distribution statistic and is used in a two-domain test depending on the confidence levels of the item The test can take different values and: S is a parameter of the Mann-Kendal method which is calculated It was mentioned above. The value of Z statistic for 95% and 99% confidence levels the percentages are considered to be 1.96 and 2.58, respectively.

2-4. Interpolation methods

In this study, for interpolation, the methods of inverse distance weighting, Global polynomials, local polynomials, radial basis functions and kriging were investigated and the most accurate method was selected. The inverse distance weighting method is based on the principle that points with shorter distances than each other with longer distances have values of variables close to each other. In this method, for each of the measuring points, a weight is considered based on the distance between those points to the position of the unknown point. These weights are then controlled by the weighting power, so that the larger powers reduce the effect of points farther from the estimated point and the smaller powers distribute the weights evenly between adjacent points. The Global polynomial method considers a short range of changes in the input data and is sensitive to neighborhood intervals in the shared window. As the window moves, the surface values in the center of each window at each point are estimated by fitting a polygon. The local polynomial method is a multivariate regression model based on all data and creates an understanding level and fits the model on the sampling points, which can be a polygonal surface with power of one, two or four. The method of radial basis functions is a function Φj (X) = Φ (X-Xj) which depends on the distance between x = Rd and the fixed-point Rd ε Xj. In this function Φ is a continuous and dependent function of any subset RdεΩ. R represents the Euclidean distance between each pair of points in the set Ω. used. Kriging is a method of estimation that is based on the logic of weighted moving average and is known as the best nonlinear linear estimator (Gaus *et al*., 2003). The condition for using the kriging method is that the variable Z has a normal distribution. Otherwise, the nonlinear kriging method should be used or the variable distribution should be normalized. The general relation of kriging is as relation 7:

$$Z^*(x_i) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (7)$$

Where, Z^* (Xi): the estimated value of the variable in position Xi, iλ: the weight of the sample i, Z (Xi): the value of the variables i and n are also the number of observations.

2-5. Accuracy assessment

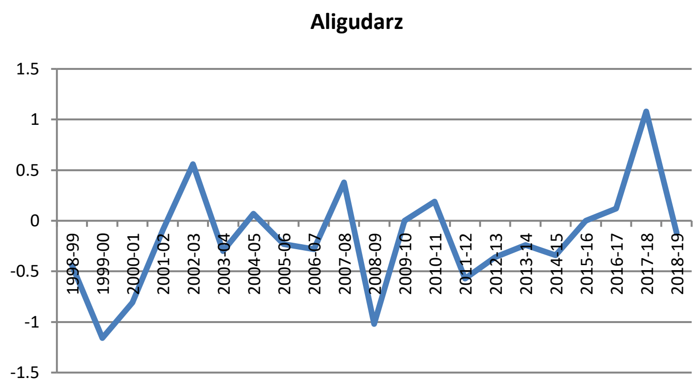
To evaluate the accuracy of each method or to select the appropriate parameter in them, there is a need for evaluation. There are several methods in this field, the most important of which is the cross-validation method. In this method, comparisons are made between measured points and estimated values using specific methods. In this way, a point is deleted and the other point is estimated using this point and applying the desired interpolation method. This point is then returned to its place and the next point is removed, and so on for all points, an estimate is made so that at the end of the two columns there are observational values and estimated values that can be able to compare them. To evaluate the accuracy and error between the observed and estimated values, there are different criteria such as the sum of the remaining squares, the mean of the remaining squares, and the use of statistical comparison methods such as analysis of variance and Chi-square. In this study, the root mean square error index (RMSE) was used to determine the appropriate method, which is known as an important indicator to show the accuracy of spatial analysis in GIS and through Equation 8 and using data Observations and predictions include:

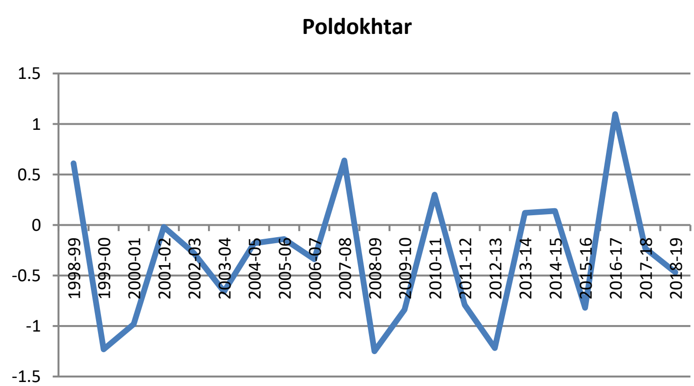
$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}((x_i) - (\overline{x}))^2}{n}} \qquad (8)$$

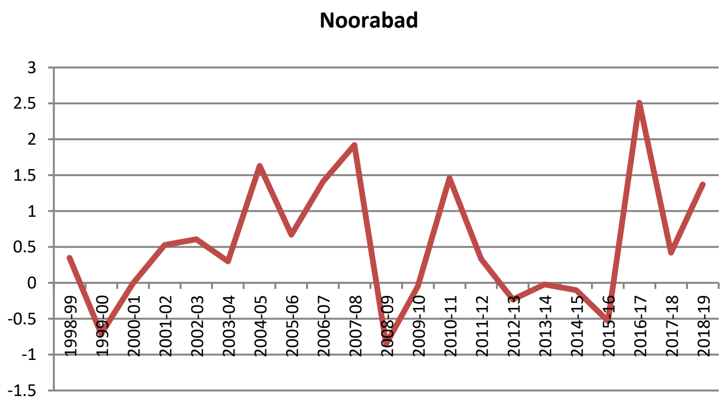
In this method, one observation point is removed in each step and that point is estimated using the other observation points. This is repeated for all observation points, and at the end there will be an estimate for each observation point. Among the various methods, the method with the lowest RMSE index is selected as the appropriate method.

3. Results and discussion

To study the drought in the Lorestan province, a diagram of trend of drought changes in synoptic stations of each city is presented as a representative of the existing stations in each city. The graphs in Figure 2 show the graph of drought changes in the cities of Lorestan province during the 21-year statistical period. According to Figure 2, the results indicate that according to the value classification scale (SPI), Aligudarz city was very dry in 1999 and 2008, with moderate humidity in 2017 and moderate drought in 2000 and in the other years has been in normal condition. According to the chart of change in the drought trend in Poldakhtar, in 2000, a positive leap occurred compared to the year 2001 and reached from the average dry state to the normal state, also in 2012 the situation was very dry, which in 2013, the situation reached normal, while in 2007 and 2008, the jump occurred negatively, so that in 1987, the situation was very dry. In Koohdasht city, a severe drought occurred in 2008, Also, drought occurred in 1999, 2008, 2012, 2009 and 2015, and in contrast to the drought situation in 2016, it was wet. The city of Khorramabad was very dry in 1999, 2008, 2011 and 2012 and very wet in 2007 and 2016. Selseleh city was extremely wet in 2010 and 2016 according to the SPI index. Doroud city was in a very dry situation in 1999 and this city has experienced moderate drought in 2000, 2008, 2012 and 2018 years. The city of Boroujerd was in a very humid condition in 2016 and was relatively dry in 2012. In Azna city according to the index standard (SPI) in 2008 and 2012 drought was very dry and in 2004 drought was very wet and the city of Noorabad in 2016 was very humid and drought in this city did not occur in this statistical period.



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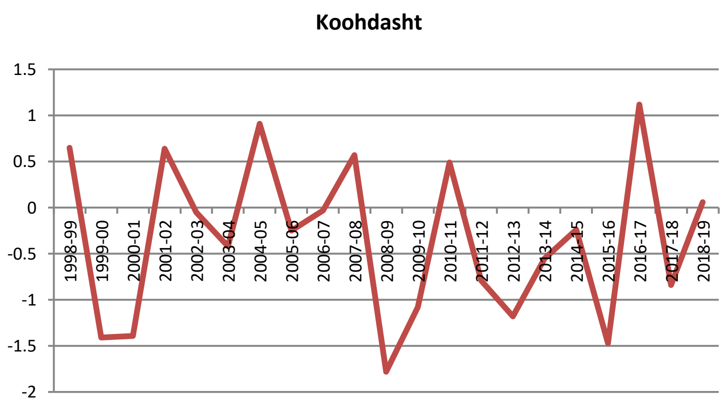
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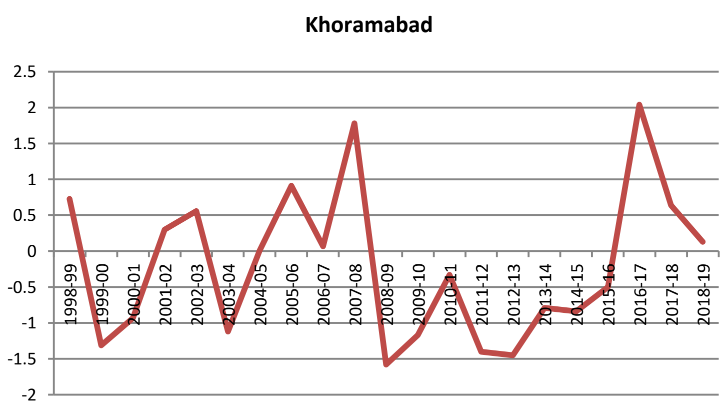
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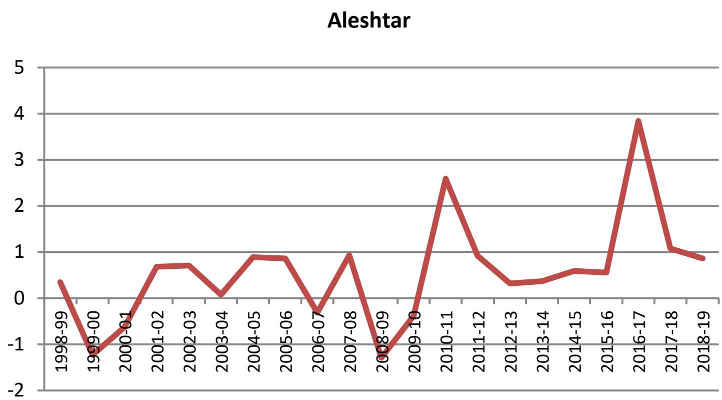
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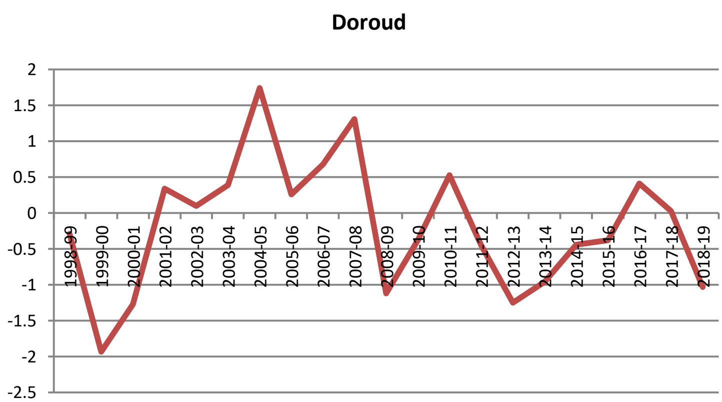
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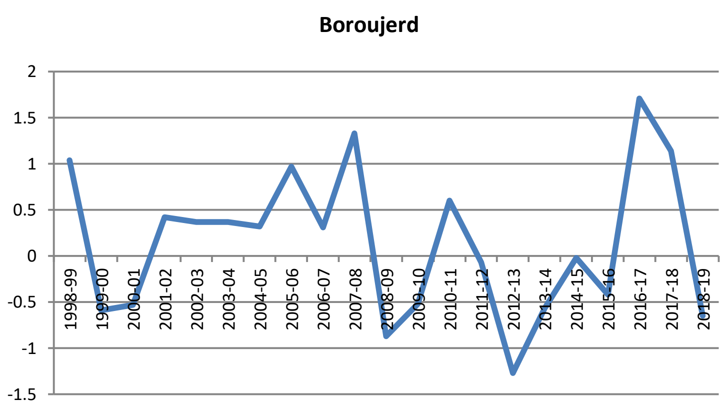
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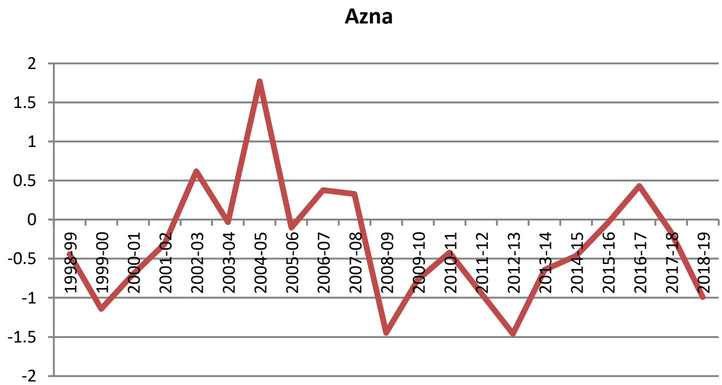

Fig 2. Chart of time trend of annual drought values of Lorestan stations

To study the trend of annual drought changes in Lorestan province in a 21-year statistical period, the Mann-Kendal test was used, the results of which are shown in Table 3. According to Table 3, at the 95% probability level, the SPI index of the Selseleh has increased and this increase is significant, which indicates a decreasing trend of drought and in other words, an increase in wet year in the city of the Selseleh. The 21-year trend of changes in the SPI index in other cities was not significant. However, in Azna, Boroujerd, Doroud and Kuhdasht stations, there has been a decreasing trend and in fact the general trend has been towards drought. In contrast, in Aligudarz, Nurabad, Poldakhtar and Khorramabad stations, there has been an increasing trend, which shows that the general trend has been wet in these stations.

Table 3. Drought trend values

city	Azna	Boroujerd	Doroud	Selseleh	Khorram abad	Kooh dasht	Pol dokhtar	Noor abad	Aligudarz
Z value	−0.393	−0.514	−0.212	2.146	0.212	−0.302	0.514	0.363	1.632

For zoning of drought in Lorestan province, first three years were defined as representative of dry, wet and normal years. These years included 2012, 2016 and 2018 which had at least three categories related to drought status (wet, dry and normal). In order to select the appropriate zoning method, different methods were evaluated. Table 4 shows the index values (RMSE) in the selected years. According to this table, kriging method was selected as the most appropriate method.

Table 4. Error index values for different interpolation methods for normal, wet and dry years

year	kr	idw	gpi	lpi	rbf
2018	0.54	0.67	0.55	0.56	0.65
2016	0.79	0.8	0.8	0.85	0.8
2012	0.77	1.05	0.79	0.86	0.93

3-1. Drought zoning in dry, wet and normal years

Figure 3 shows the drought situation in 2012, By examining the drought monitoring that occurred in 2012, most cities in Lorestan province are affected by drought this year. The main core of the drought this year is located on the west, south and northwest and an area of the center of the province, and in contrast to parts of the center and east of the province at the same time had a normal situation.

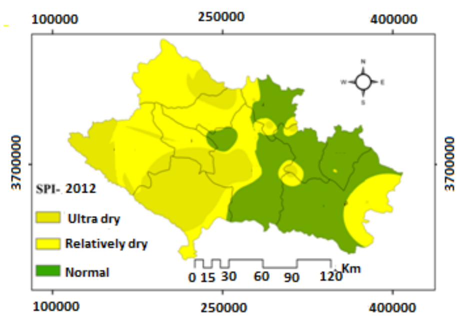

Fig 3. SPI spatial zoning of 2012

Figure 4 shows the zoning of the drought in 1995, in which the situation has changed and the regime is wet. At this time, the core of the maximum wet season intensity is related to the north of the province, which includes Delfan city and part of Selseleh city. Moving from north to south, the wet intensity has decreased until the drought situation in the southern strip of Lorestan province has reached normal.

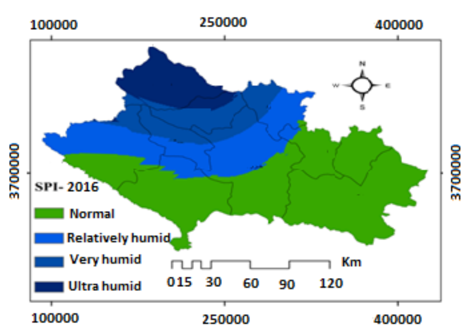

Fig 4. SPI spatial zoning of 2016

Figure 5 shows the drought situation in the province in 2018, which shows that in most parts of the drought has reached a normal state, cities located in the western and northwestern parts of the province, relative prevailing wet year. The cities in the eastern part of the province are in a state of relative drought, as well as the northern, central and southern parts of the province, which include parts of Boroujerd, Doroud, Khorramabad and Poldakhtar .

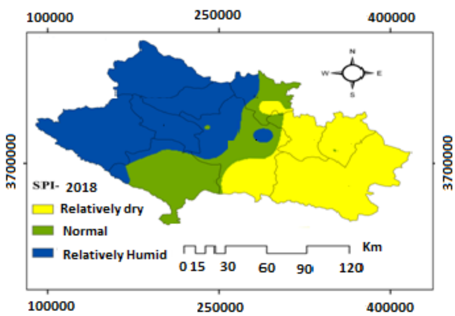

Fig 5. SPI spatial zoning of 2018

Table 5 contains the number of different drought categories for selected stations in Lorestan province, which shows the general drought situation of the station in the study period. According to this table, Khorramabad station as the center of the province has had 13 normal years, 3 relatively dry years, 3 very dry years and 2 very wet years. According to this table, the driest station can be introduced as Koohdasht station; because it has one ultra-dry year, 3 very dry years and 2 relatively dry years. In contrast, Noorabad station is introduced as the wettest station because it has one wet year, 2 very wet years and 3 relatively wet years.

Table 5. Number of different drought categories for selected stations over a 21-year period

station	Ultra wet	Very wet	Relatively moist	normal	Relatively dry	Very dry	Ultra dry
Khorramabad	0	2	0	13	3	3	0
Koohdasht	0	0	1	14	2	3	1
Noorabad	1	2	3	15	0	0	0
Selseleh	0	1	0	17	2	1	0
Poldokhtar	0	0	1	16	1	3	0
Doroud	0	1	1	14	4	0	1
Boroujerd	0	1	3	16	1	0	0
Aligudarz	0	1	3	12	3	2	0
Azna	0	1	0	15	3	2	0

4. Conclusion

In this study, the climatic situation of Lorestan province in Iran during a 21-year statistical period was studied using the standard Precipitation index (SPI). The results show that according to the scale of quantification (SPI), the cities of Doroud in 1999 and Koohdasht in 2008 are ultra-dry and the Selseleh in 2010 and 2016 and the Noorabad was ultra-wet in 2016. Examining the drought trend using Mann-Kendal test, it was found that the city of Selseleh has a positive and significant trend at the probability level of 95% and the other of the cities do not have a significant trend. By examining the time series index (SPI) of different stations, the year 2012 was selected as the representative of dry years, the year 2016 as the representative of wet years and the year 2018 as the representative of normal years. Also, for zoning the province's drought in 2012, 2016 and 2018, the kriging method was used because it had the lowest error rate compared to other methods. Drought zoning maps in Lorestan province in 2012, 2016 and 2018 show that in 2012 and 2018, the eastern parts of Lorestan province faced more drought. In general, the driest station can be introduced as Koohdasht and the wettest station can be introduced as Noorabad. According to the results of this study and the occurrence of various droughts in different parts of the province, to deal with the effects of this phenomenon, proper planning of water resources and insurance of agricultural products, especially in the city of Koohdasht, which more than other parts of the province with Drought has been suggested.

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